OICA Statements for PMP IWG Meeting Sep. 22, 2022

Note: All comments made in this complementary document by OICA should also be read in conjunction with the OICA comments to the draft GTR. They may not be 100% aligned at this time.

Disclaimer: OICA continue to find technical issues in the draft GTR and identify issues that are not addressed. Opportunity for more discussion is required.

Version 22.09.2022

OUTLINE

TOPIC

Cooling Air Temperature

Brake Enclosure Design Proposal

Definition of Roadload Data

Consideration of Engine Friction

Method for Electrified Vehicles

WL/DM Concept – need to update

Bedding Procedure

Multiple Filter Holder

PN procedure

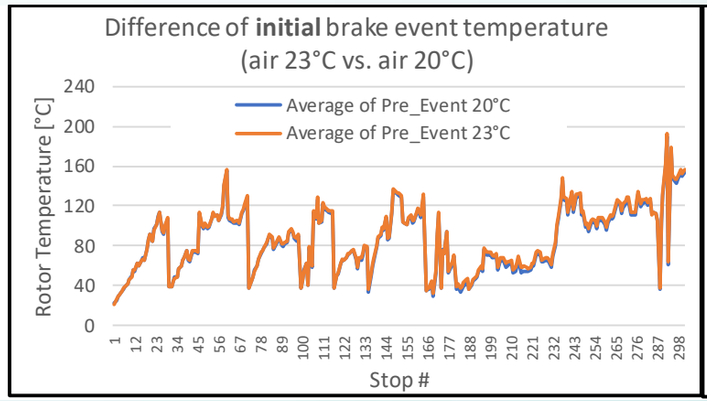
Family building

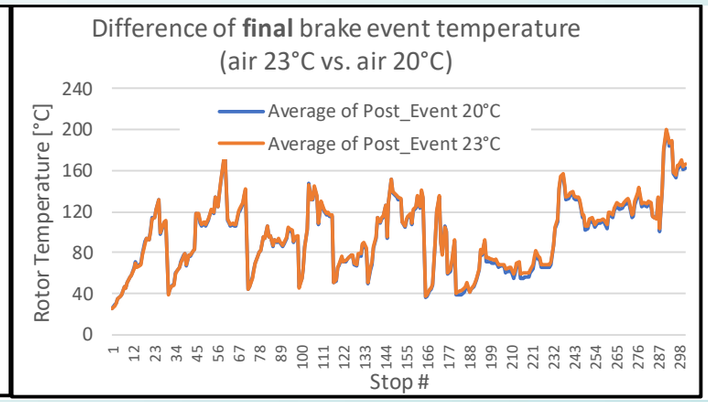
COOLING AIR TEMPERATURE (23°C VS. 20°C)

- OICA requests to change the cooling air temperature from 20°C to 23°C – in-line with WLTP exhaust testing
- Brake temperature and emisson data show no impact

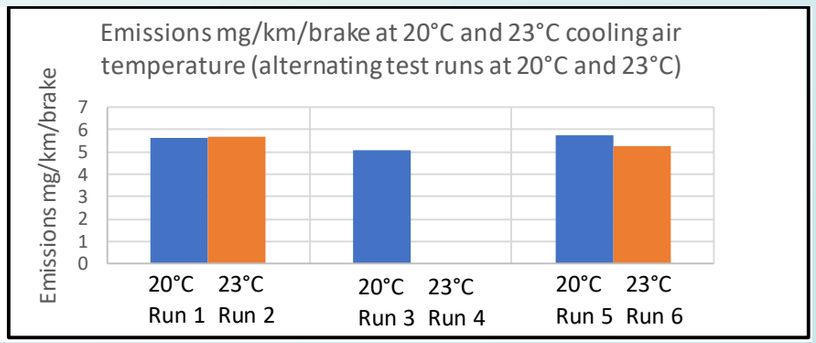
Influence of cooling air temperature (23°C vs. 20°C) in WLTP Brake Emission Procedure

	Air temperature	Test #	Average initial temperature	Average final temperature
Disc tempe-rature	20°C	1	85.8	96.0
		3		
		5		
	23°C	2	87.4	97.5
		4		
		6		
	Difference for 23°C vs. 20°C		1.6	1.5





	Air temperature	Test #	PM10	Average PM10
PM10	20°C	1	5.60	5.47
		3	5.06	
		5	5.74	
	23°C	2	5.70	5.50
		4	N/A	
		6	5.29	
	Difference for 23°C vs. 20°C			0.03



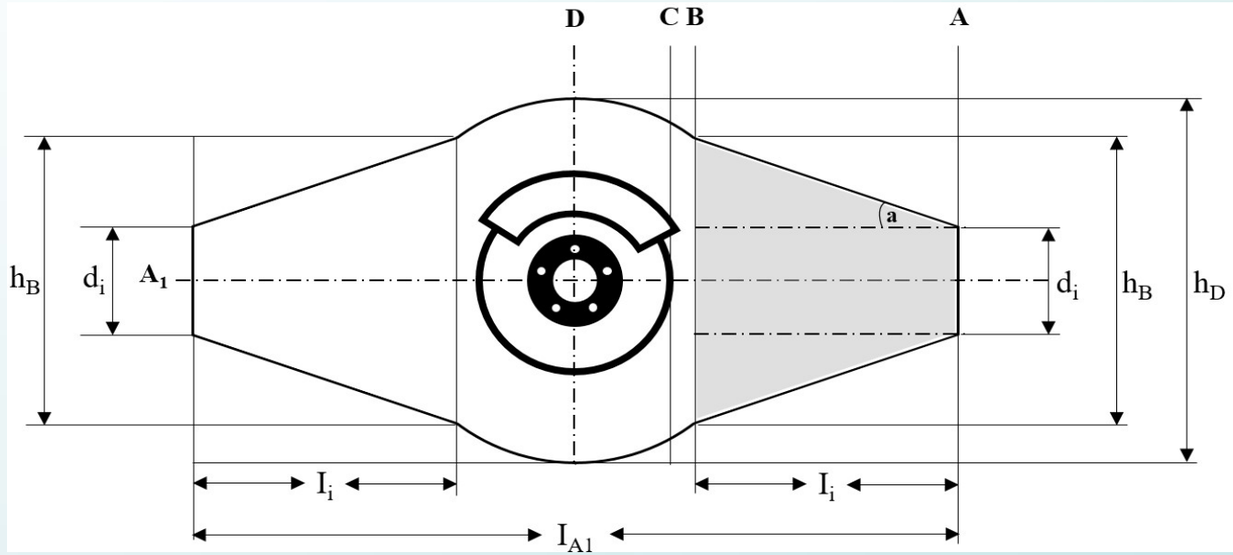
OEM 1:
The increase of cooling air temperature from 20 to 23°C generated neglectable disc temperature difference during the tests (less 2°C on average).
This temperature difference did not generate any noticeable differences in the PM10 emissions.

BRAKE ENCLOSURE DESIGN PROPOSAL

In order to reduce particle losses and lab-to-lab variability, the enclosure design parameters need to be tightened

ENCLOSURE PROPOSAL

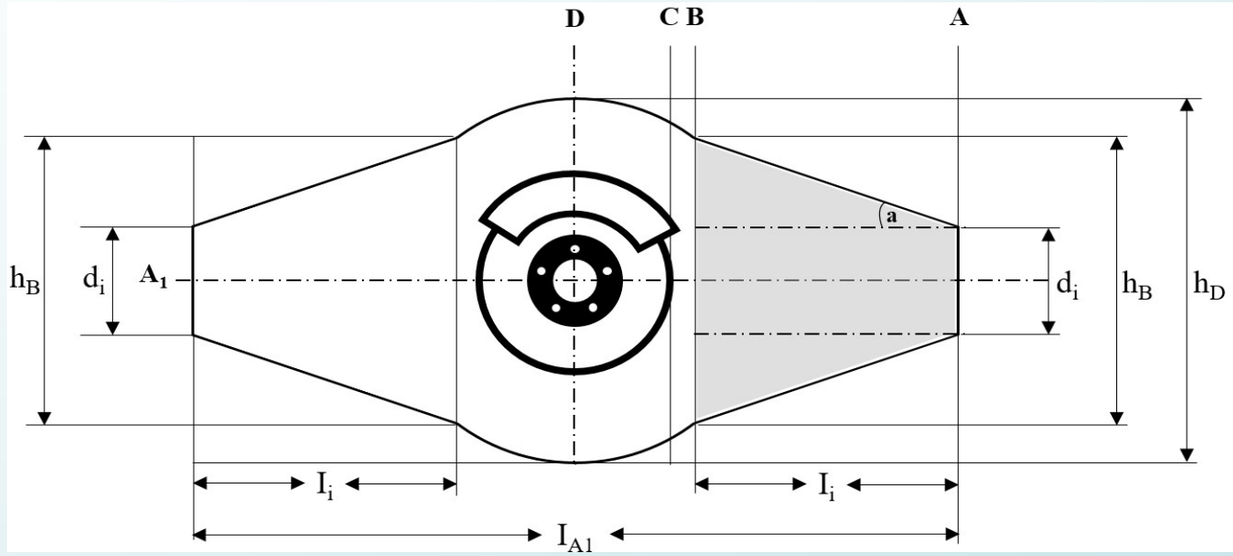
- Input from (7) OEMs



Symbol	Description	Draft GTR	Prelim recommendation tbc.
d_i	Inlet & outlet Ø	175 to 225mm	200mm ± 5mm & 203.2mm ± 5mm (8" duct)
h_B	Length of plane B (enclosure)		600mm
h_D	Length of plane D (enclosure)	600 to 750mm	600mm
a	Transition angle	15° to 30°	tbd
h_B / h_D	Ratio of heights plane B – plane D	> 60%	100%
	Radius of largest disc (dist. planes B & C)		225mm
	Cross section depth at plane B	= h_B	500mm (alt. 600mm)
	Max. axial depth at plane D	400 to 500mm	500mm (alt. 600mm)
I_{A1}	Length of plane A1 (enclosure)	1200 to 1400mm	1400mm (alt. 1600mm)

ENCLOSURE PROPOSAL

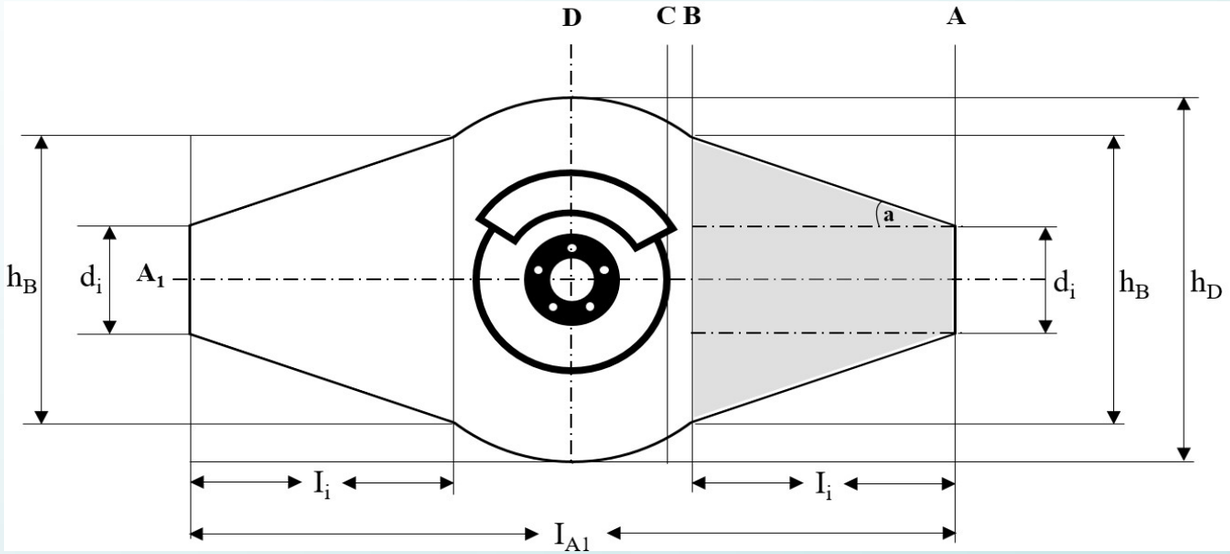
- Input from (7) OEMs



Symbol	Description	Draft GTR	Prelim recommendation tbc.
I_i	Length of inlet or the outlet of enclosure		400mm tbd
L1	Min length of straight duct at inlet of brake enclosure	2*di (if bend applied)	2*di (is this needed?)
	Angle of bend after enclosure	0° to 90°	90° or 0° tbd
L2	Min length from last disturbance & upstream of sampling plane		6*di (~ 1200mm)
L3	Min length to next disturbance & downstream of sampling plane	2*di	2*di (~ 400mm)
L4	Min length from last disturbance & upstream of airflow measurement element		5*di tbd (~1000mm?)

ENCLOSURE PROPOSAL

- Input from (7) OEMs



Symbol	Description	Draft GTR	Prelim recommendation tbc.
L5	Min length to next disturbance & downstream of airflow measurement element		2*di tbd (400mm?)
r_B	Bending radius of the cooling air duct		3*di tbd
R1	Radius of bend downstream of sampling plane (or upstream of sampling plane in a different layout)		tbd
	Where noted above and several other parameters remain work in progress		tbd

DEFINITION OF ROAD LOAD DATA

- **OICA strongly recommends the use of vehicle specific F-terms for all vehicles**
- **F-terms exactly describe the real vehicle movement resistances and is already available with homologation documentation**

Definition of Road Loads for the Brake Emission Procedure

WORK IN PROGRESS

Current GTR defines road loads at a fixed level of 13% for all vehicles and vehicle types (passenger and commercial).

Data being collected for ISV-CO2 (work in progress) suggests that this simplification underestimates the real influence of road loads for commercial vehicles and slightly overestimates for passenger cars**.**

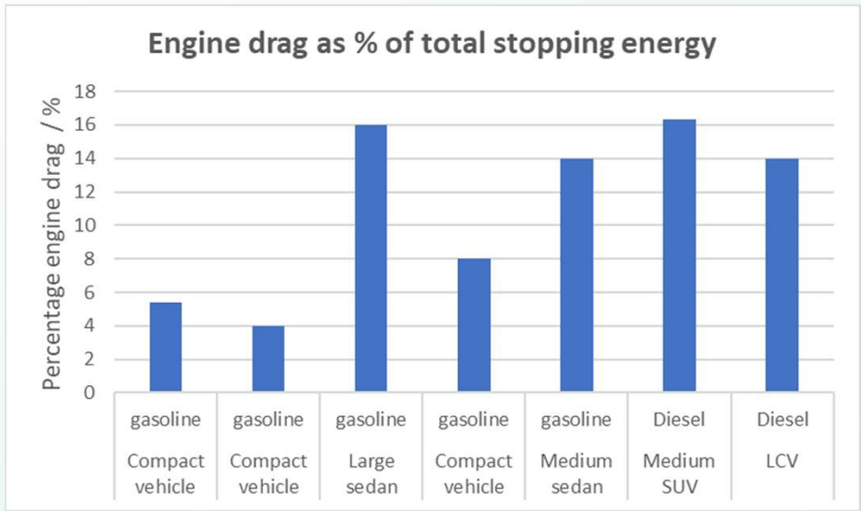
OICA strongly recommends the usage of vehicle specific F-Terms for all vehicles. F-Terms exactly describe the real vehicle movement resistances.

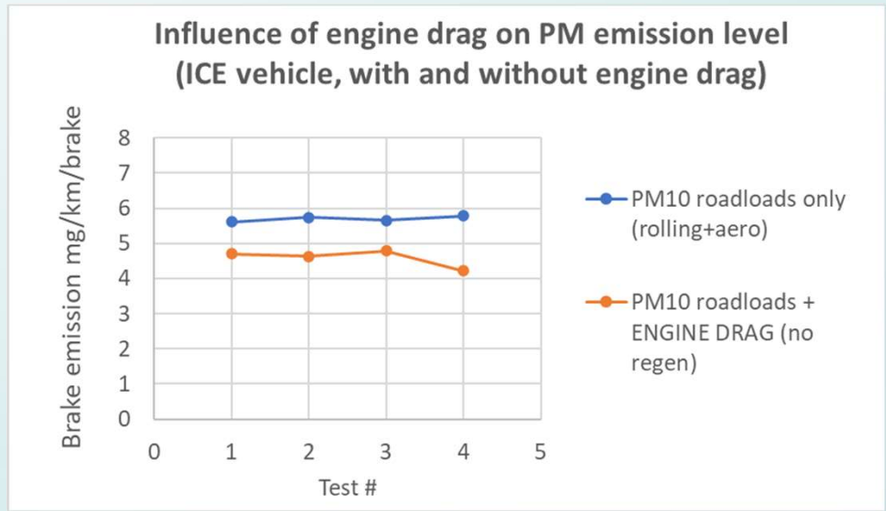
Already today, F-Terms are available for all vehicles, as they are part of vehicle homologation documentation**.**

CONSIDERATION OF ENGINE DRAG

Influence of engine friction on dissipation of stopping energy cannot be neglected and must be included in GTR

SIGNIFICANCE OF ENGINE DRAG FOR ENERGY DISSIPATION AND BRAKE EMISSIONS





Typically, engine friction reduce the required use of the friction brake in range of 4% - to 16% in the WLTP Brake Cycle

Tests show brake emission reduction corresponding to engine drag

Engine friction significantly influences energy share of friction brake in Brake-WLTP cycle, and shall be considered for all electrified vehicles

METHOD FOR BRAKE EMISSION MEASUREMENT OF ELECTRIFIED VEHICLES

- **Future vehicles will be electrified**
- **Vehicle electrification substantially reduces brake wear particle emissions**
- **The GTR needs to address cover this in a scientifically and technically correct way**

ENGINE DRAG AND PARALLEL HYBRID TECHNOLOGIES

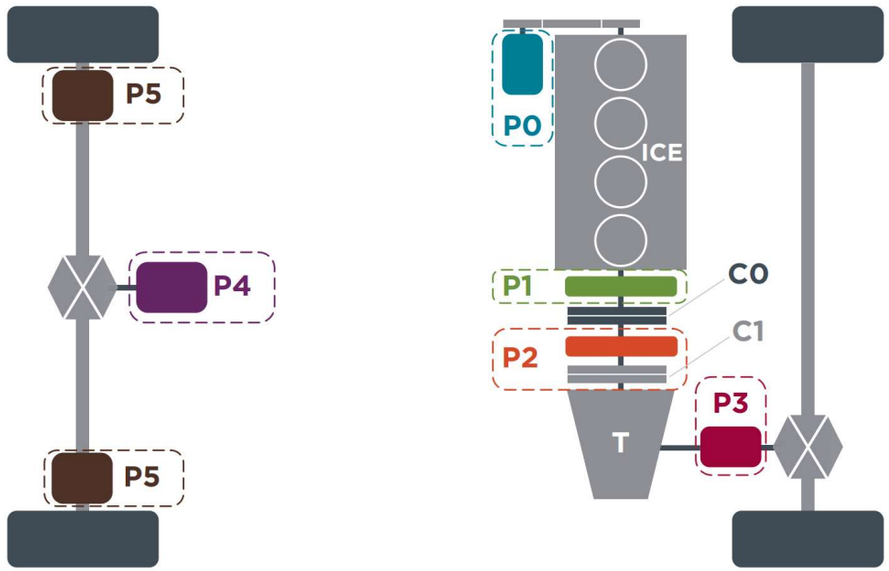


Figure 5. Components defining the architectures P0 to P5 of parallel hybrid powertrains. Cx: Clutch x, T: Transmission; Px: Position of electric machine(s) in each configuration x. *Sources:* Bao et al. (2017), Eckenfels et al. (2018)

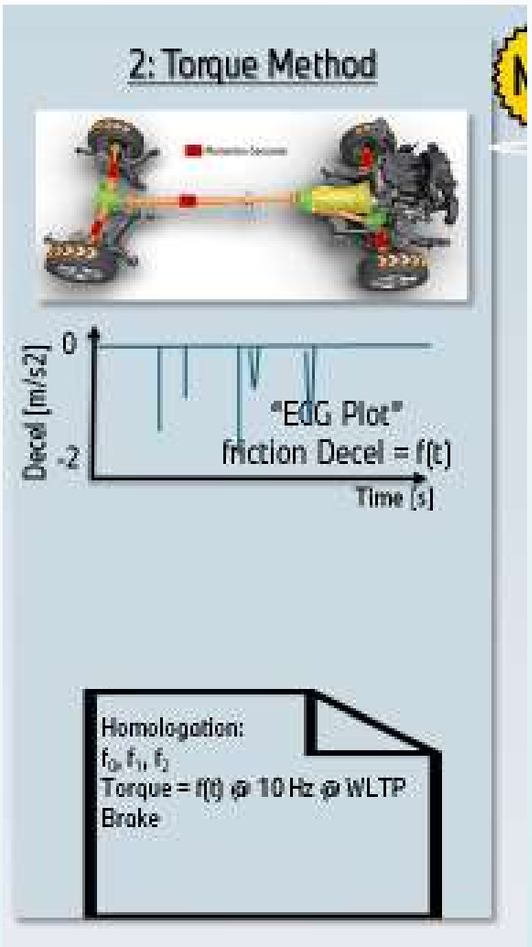
ICCT, White Paper 2022

- **If Hybrid has decoupling (C0, C1), the engine drag is much reduced. For emission testing the overall reduction of friction braking shall be determined by a validated model, considering all "losses":**

F(residual friction brake) = F(decel) – F(rollingresist) –F(airresist)– F(engine drag) – F(recuperation) – F(…)

- **For Hybrid emission testing according to the "JRC-Method" the "worst case" operation is tested, and engine drag must be considered**

DETERMINATION OF NON-FRICTION-BRAKING CONTRIBUTION FOR A SINGLE BRAKE/VEHICLE-COMBINATION

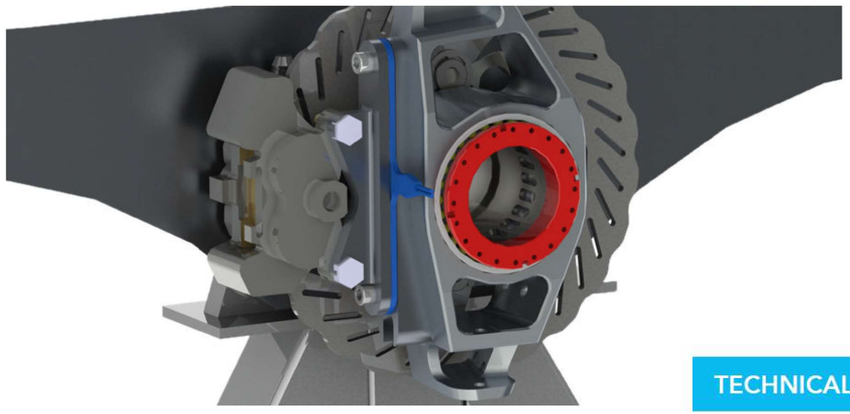


- The method uses time based brake torque signal provided by CAE model
- The model should be validated by testing authorities (e.g. TÜV) using physical measurements*.
- Process proposal:
- The validation occurs by comparison of calculated and measured torque traces during specified brake applications.
- Verification brake applications are done at identical test conditions for the model and vehicle test – for two different state of charge (SoC) - nominal and close to max.
- Brake torque measurement can be done:
  - On test track
  - On chassis dynamometer
- In every of above cases, brake calipers must be instrumented

* If necessary, testing laboratory can re-validate tested vehicle

MEASUREMENT OF BRAKE TORQUE

- **Example of Brake torque measurement**

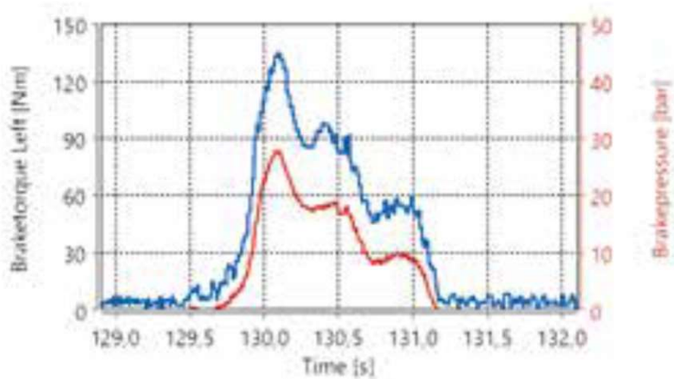


AVL Brake torque measurement, 2020

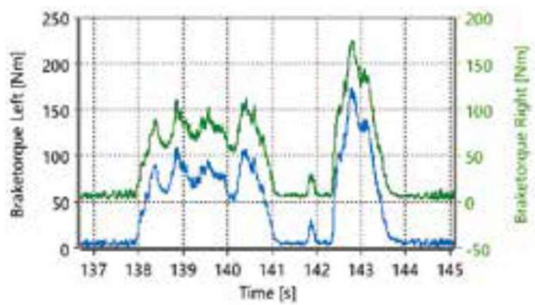
TECHNICAL SPECIFICATIONS	
Operating principle	Piezoelectric, charge output
Torque output	Mz axial
Dynamic torque range	Virtually unlimited (friction-type connection)
Accuracy[1]	±1% FSO
Resolution[2]	0.3 Nm
Natural frequency	>120 kHz
Standard bolt diameters	M6 ... M14
Brake types	Radial, axial
Charge amplifier	Analog (0 … 5 V)

[1] Empirically determined, depending on test set up
[2] At 5 kNm measuring range

AVL, 4/2022

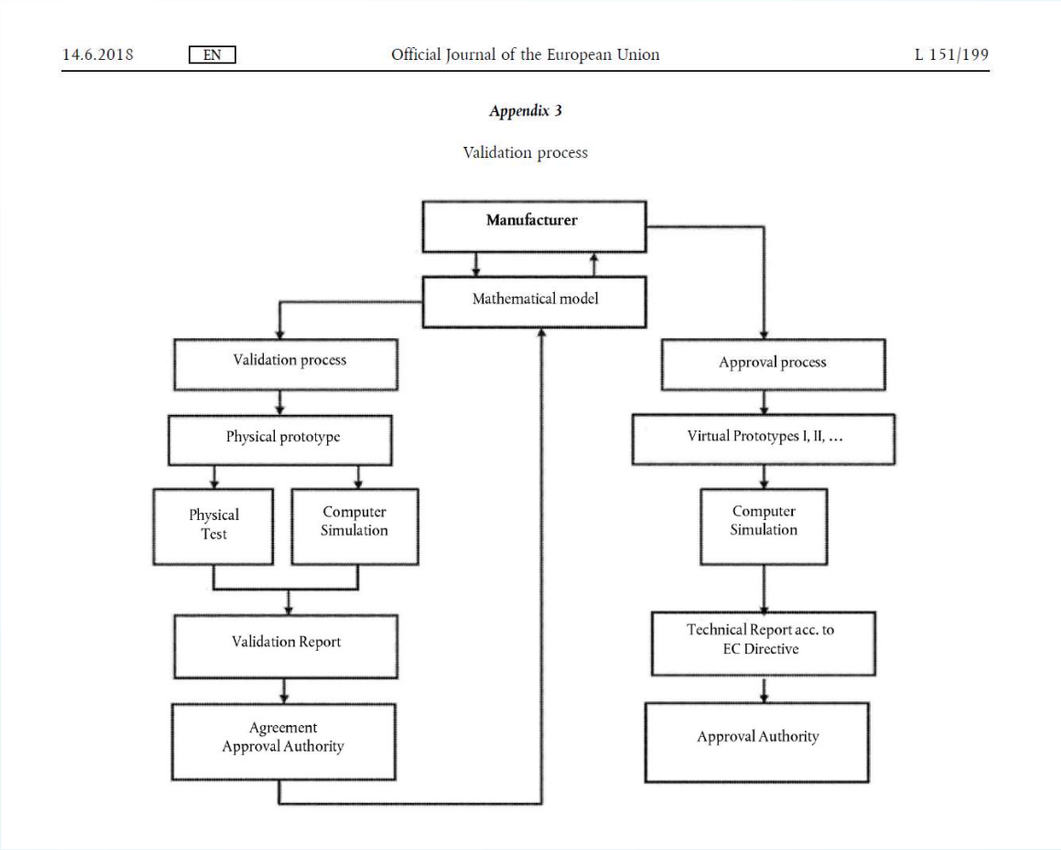


Analyze fading and correlation to the brake system Pressure (AVL, 4/2022)



Balancing between different brakes (AVL, 4/2022)

VALIDATION OF MODEL – REGULATION (EU) 2018/858



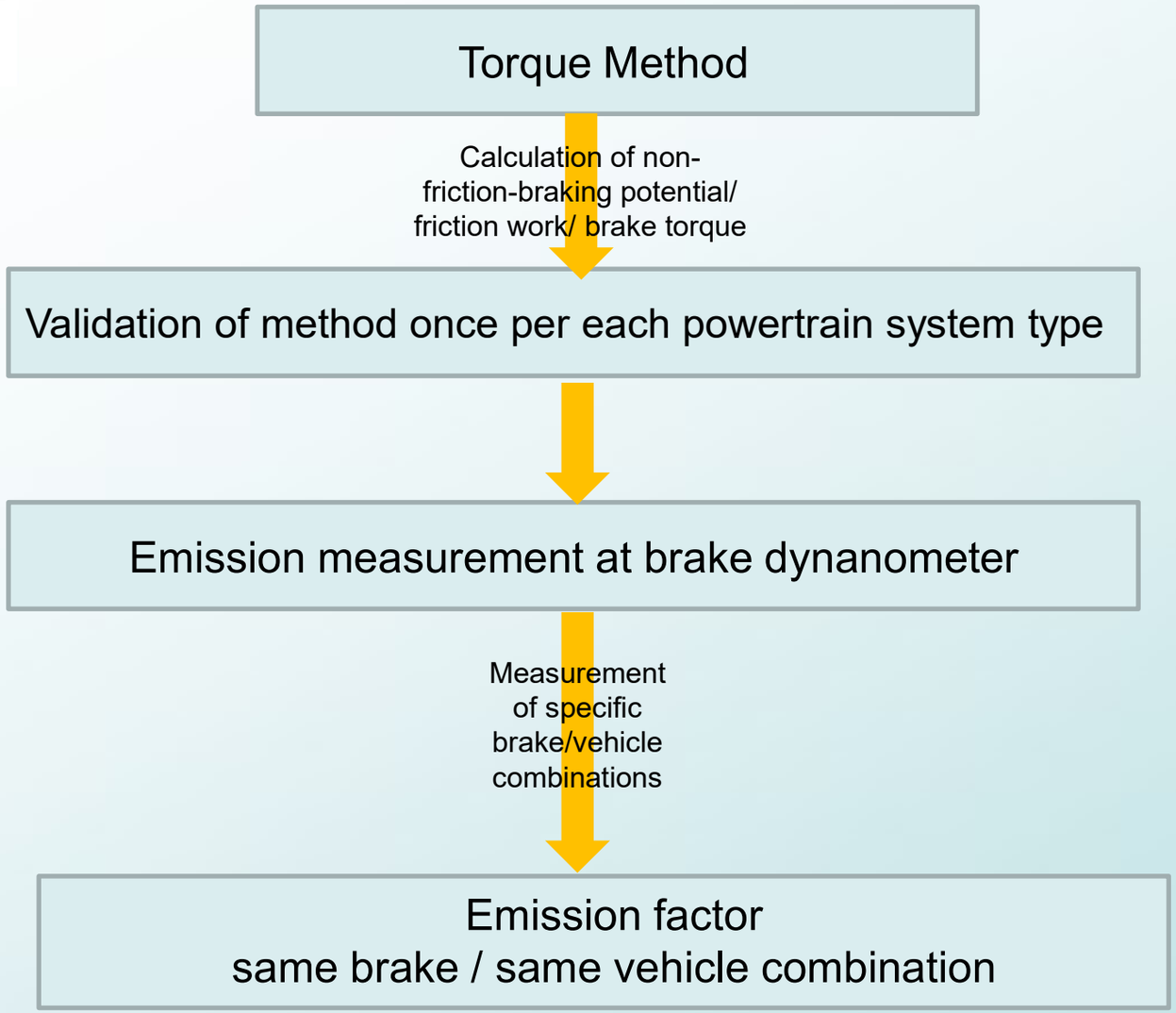
14.6.2018 EN Official Journal of the European Union L 151/199

Appendix 3

Validation process

- **REGULATION (EU) 2018/858 describes the validation process of a mathematical model**
- **Approval process occurs via presentation of the computer simulation to the Approval Authority**
- **For the Torque method a validated computer simulation and a physical emission test is proposed**
- **Need to work out this approach with approval authorities**

BRAKE EMISSION MEASUREMENT OF ELECTRIFIED VEHICLES



1. Define method to determine the behavior of the brake in combination with the powertrain
2. Validate to corresponding method/model
3. Use output from the validated model for running Brake WLTP on brake dynamometer to measure brake emissions).
   Vehicle/Model is started with full battery and recharging is considered
4. Measure Front/Rear brake and calculated vehicle emission factor (mg/km)

WL/DM CONCEPT

- The temperature requirements do not work for light-weight materials, i.e. ceramic brake rotors
- WL/DM concept needs updating

CERAMIC BRAKE ROTORS AND OTHER LIGHTWEIGHT MATERIAL

Status quo GTR

- WLTP-Brake temperature ranges are determined by the WL/DM ratio
- However, disc mass (DM) considers only gray cast iron (GJL) rotors
- **Lightweight materials / rotor concepts are not taken into account**

Table 1 – Default temperature metrics and limits for brakes during Trip #10 of the WLTP-Brake Cycle

WL/DM Groups	Average [A_1] [°C]	IBT [A_2] ± Tolerance [°C]	FBT [A_3] ±Tolerance [°C]
≤45[7]	>50	55±15	85±25
>45 & ≤65	>55	65±15	105±25
>65 & ≤85	>60	75±15	120±25
>85	>65	85±15	140±25

Example:
Rotor material impacts DM :

$$\frac{\rho_{GJL}}{\rho_{CSiC}} \approx 3 \Leftrightarrow \frac{DM_{GJL}}{DM_{CSiC}} \geq 2$$

→ If, for the same vehicle, a GJL rotor would be categorized in group <45, the respective ceramic rotor (CSiC), with equal or even larger dimensions, would be “catapulted” in group >85
→ Unrealistic group classification if specific heat capacity is not considered.

Consequences:

1. Innovative lightweight-brake rotors (ex. CSiC ceramic rotors) would be penalized through disproportionately high temperatures
2. The required high IBT & FBT classes in combination with large ceramic rotors, imply reduced cooling air flows which could impact the PM measuring ability

CERAMIC BRAKE ROTORS AND OTHER LIGHTWEIGHT MATERIAL

Gray cast iron
Carbon ceramic

Brake	GG		PCCB (Vgl. GG)	
Vehicle speed (Soll: 44,11)	44,22		44,25 (+0,03)	
avg. ambient T	39,4		41,1 (+1,7)	
	Mittel	Maximum	Mittel	Maximum
T_wheel house FL	57	66	59 (+2)	69 (+3)
T_wheel house FR	58	69	61 (+3)	70 (+1)
T_wheel house RL	45	54	46 (+1)	55 (+1)
T_wheel house RR	45	51	47 (+2)	56 (+5)
T_disc FL	**78**	**112**	**71 (-7)**	**122 (+10)**
T_disc FR	**85**	**121**	**81 (-4)**	**120 (-1)**
T_disc RL	**63**	**82**	**63 (±0)**	**104 (+22)**
T_disc RR	**62**	**81**	**64 (+2)**	**108 (+27)**

Proving ground: Nardò, Test vehicle: sportscar, Brake systems: gray-cast iron vs. carbon ceramic brake, both in serial spec
→ Comparable testing conditions confirmed!

In comparison to the gray cast iron disc the carbon ceramic disc shows similar temperature ranges in the Trip 10 of the WLTP Brake.

CERAMIC BRAKE ROTORS AND OTHER LIGHTWEIGHT MATERIAL

Proposal A:

*** Standardized-factors shall be elaborated for relevant brake rotor materials (ex. S CSiC = 1,7)**
*** Factors should be introduced in the GTR for non-gray cast iron friction rings (non-GJL)**
*** No cp-measurement at local brake test facilities / laboratories needed**

$$s = \frac{c_{P\ Friction\ Ring}}{c_{P\ GJL}} \approx 1{,}7^{**}$$

* The factors represent a **normalized ratio to the thermal capacity** of the gray cast iron and should be multiplied by the real disc mass (non-GJL) in order to obtain the temperature group (WL/DM group)

$$Group_{non-GJL\ Rotors} = \frac{WL}{DM \cdot s}$$

*** Known matrix (groups and temperature ranges) remain unchanged**

(Physical background - temperature change (for a given heat flow ΔQ) depends on mass and spec. heat capacity c_P)

$$\frac{dT_{Disc}}{dt} = \frac{\Delta \dot{Q}}{m \cdot c_{P\ Disc}}$$

Proposal B: Note the possibility to use real vehicle temperature data to find the right WL/DM class **for non-gray cast iron friction rings (non-GJL)** in the GTR

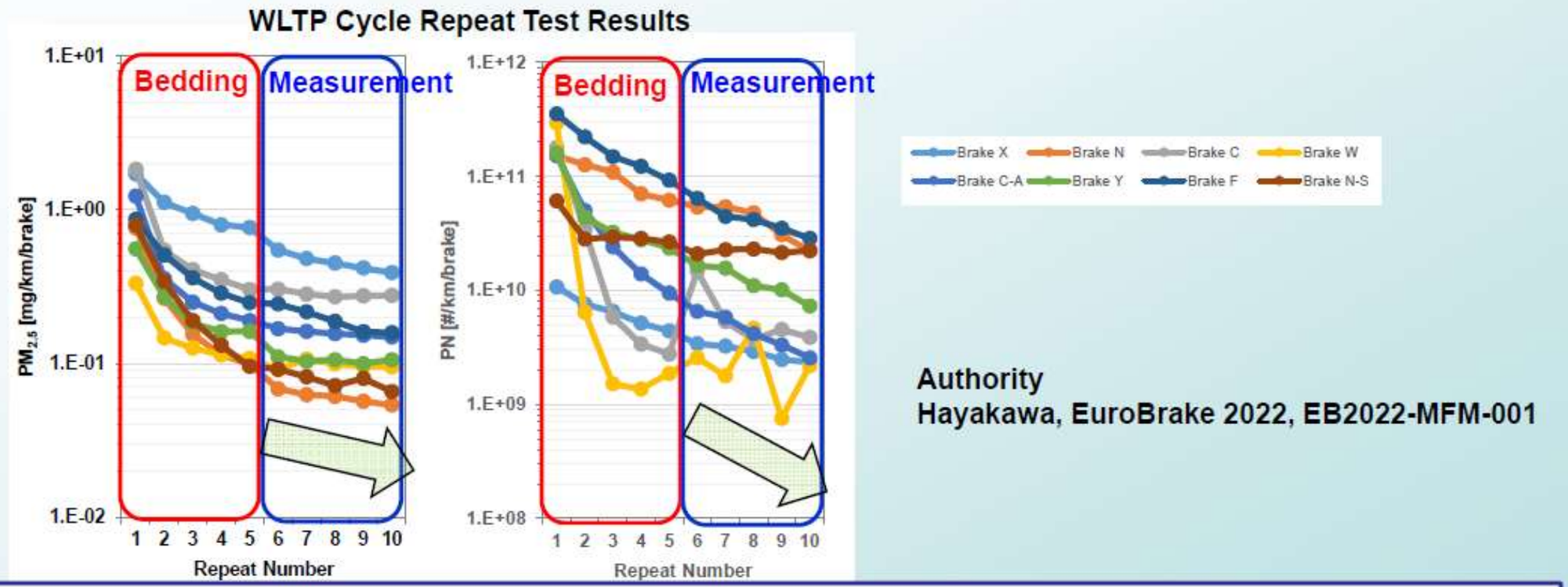
- **The temperature requirements do not work for light-weight material, i.e. ceramic brake rotors**
- **WL/DM concept needs update**

BEDDING PROCEDURE

- The current bedding procedure of 5x WLTP needs further investigation.
- OICA proposes a revision of the bedding procedure

Bedding Procedure / Multi-sampling
JAMA findings on NAO

Comment TWO regarding measurement Number of cycles

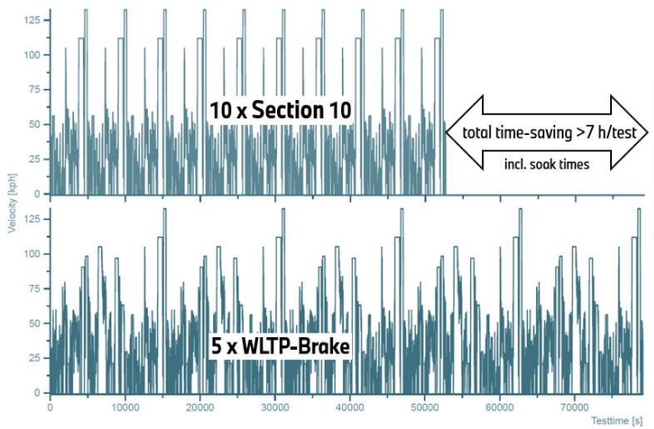


Authority
Hayakawa, EuroBrake 2022, EB2022-MFM-001

- Investigations of JAMA show that more bedding is required to achieve stable results
- Investigations of JAMA show that stability can only be determined with multiple repetitions of emission measurements

Bedding Procedure
PMP Task Force 3 discussions

INVESTIGATED BEDDING CYCLES



	Duration* [h]	Number of stops [-]	Braking power [Wh]
10 x Section 10	14.63	1140	113.38
5 x WLTP-Brake	21.98	4545	168.89
Delta	**7.35**	**3405**	**55.51**

*w/o soak times

SUMMARY AND CONCLUSION

- Both bedding procedures (5 x WLTP-brake and 10 x section 10) have been investigated
- The results show no significant influence:
  - Neither on temperatures
  - Nor on emissions
- However, there has been no examination of different flows or variation of other tests parameters
- At this point in time the differences are considered to be within the expected repeatability of the overall tests/procedure
- The overall bedding procedure duration can be reduced by more than 7 h per test

→ PMP has to decide how to proceed with the implementation of the method or additional experiments

→ How many emission tests should be conducted after the bedding?

Details of the investigation may be discussed in a separate meeting

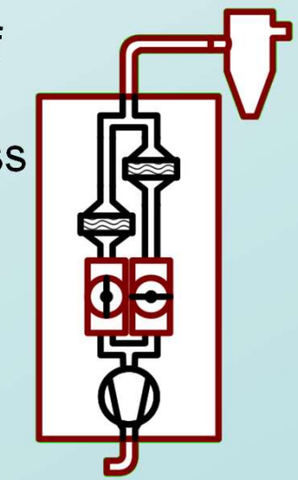
- BMW investigated a shortened bedding procedure to reduce testing time and proposed “10 x Trip 10” instead of “5 x WLTP Brake” bedding
- However, only one set of NAO has been tested
- Proposal: Investigation of JAMA and/or others to check if increased number of “trip 10 bedding” could improve stability of NAO within the currently foreseen time effort.
- **OICA suggests revision of bedding proceedure**

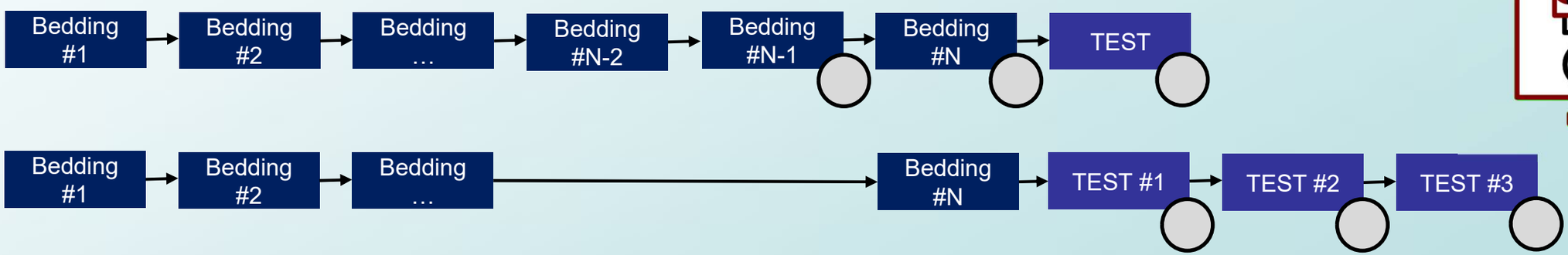
MULTIPLE FILTER HOLDERS

- An option for multiple sampling should be added in order to run automated repetitive testing

MULTIPLE SAMPLING

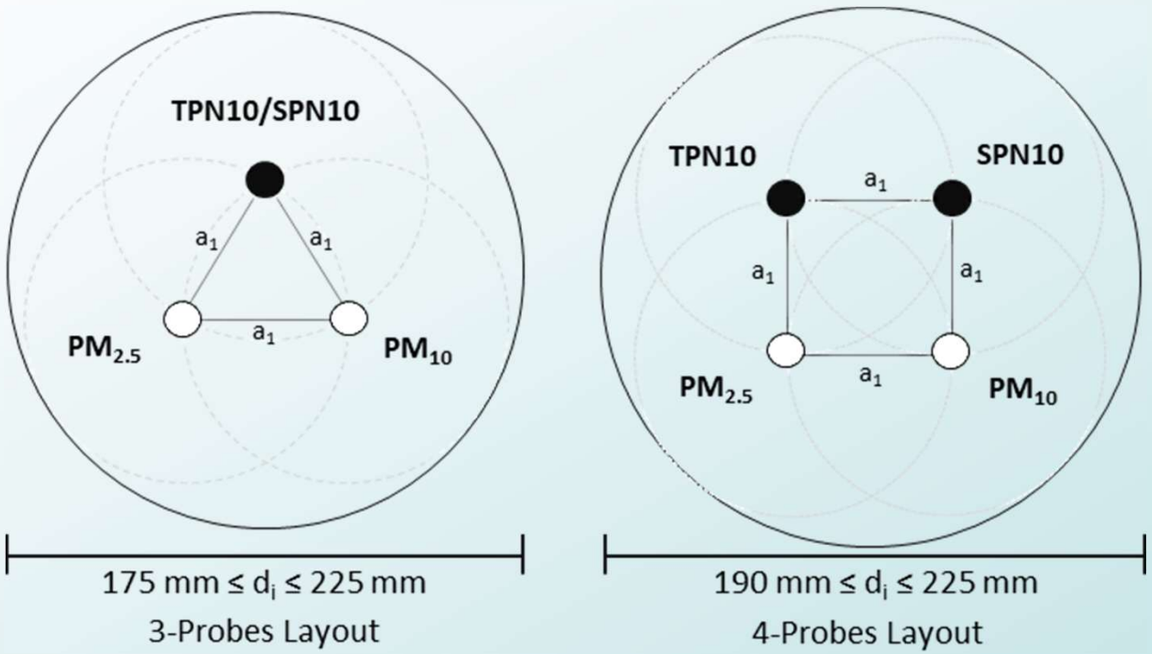
- Investigations show that stability of brake systems can only be determined by multiple, consecutive measurements.
- OICA therefore proposes the usage of multi-sampling systems (e.g. 3 filters) to enable automated testing with one brake system test setup.
- Due to the lack of very volatile particles the handling and storage of the filters etc. should be of minor concern.
- To OICA's understanding, investigations on influence of losses on such systems are in progress
- To OICA's understanding, enhanced instruments with little effect on flow, losses etc. are in development





- To address the topics of stable brake systems and reliable and reproducible results both topics need further investigation and introduction to the proposal draft GTR.

QUESTION FOR CLARIFICATION ON SEPARATE PM10 and PM2.5 SAMPLING PROBES

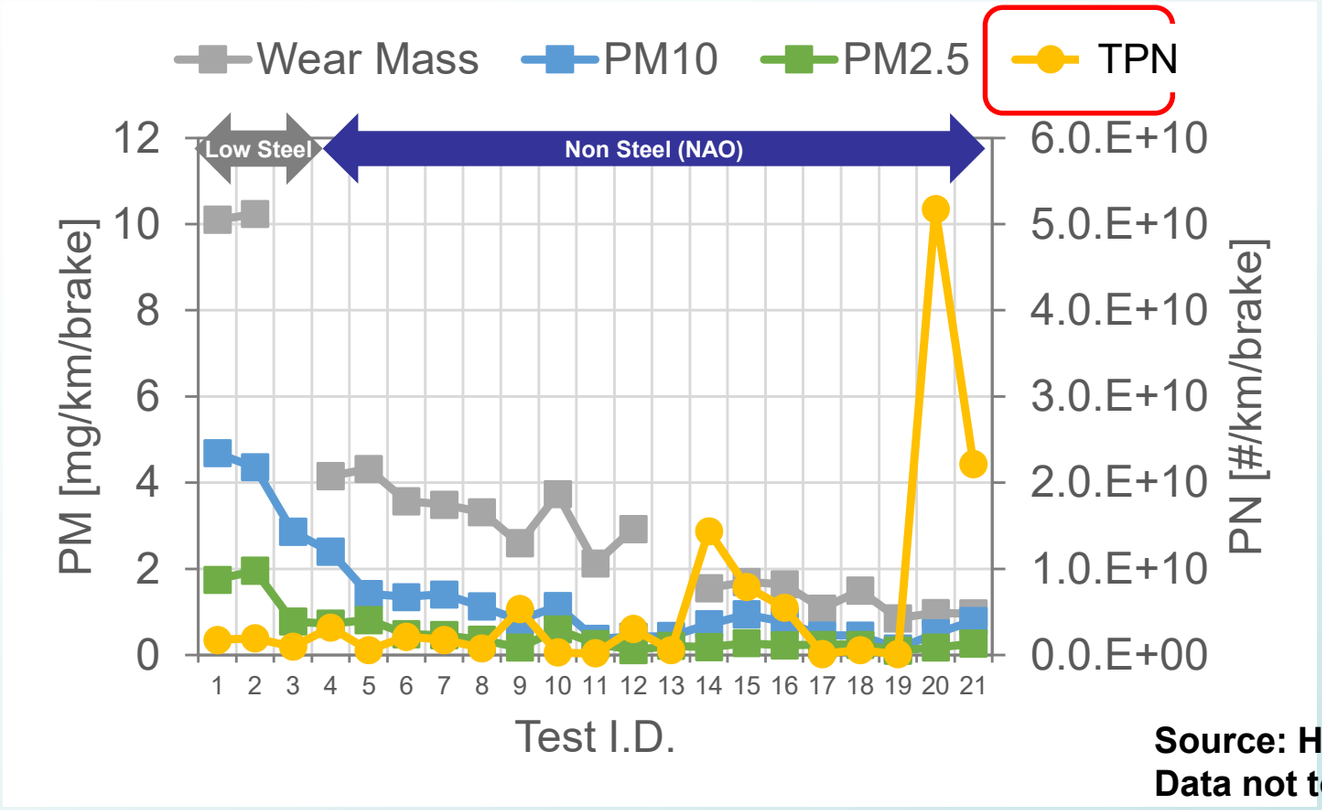


In PM measurements, PM2.5 and PM10 are to be measured separately with separate probes without using cascade impactors.
PM10 includes PM2.5, and there is no necessity to measure PM10 and PM2.5 using separate probes.
We would like to know the reason for this method.

PARTICLE NUMBER MEASUREMENTS

- TPN (Total Particle Number) brake wear particle measurements are not reproducible
- A determination of TPN is not expedient and should be omitted from the GTR

CONCERNS REGARDING PN



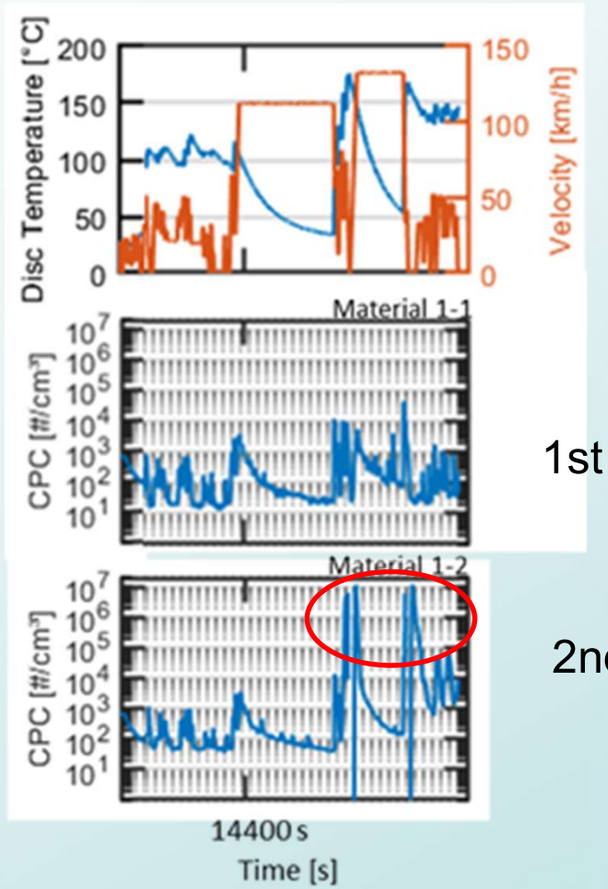
Test ID	Condistions
1	Low Steel I 1 m3/min
2	Low Steel I 4 m3/min
3	Low Steel II 4 m3/min
4	Non Steel I 1 m3/min
5	Non Steel II 1 m3/min Lab. A
6	Non Steel II 1 m3/min Lab. B
7	Non Steel II 1 m3/min Lab. C
8	Non Steel II 1 m3/min Lab. D
9	Non Steel II 1 m3/min Lab. F
10	Non Steel III 1 m3/min
11	Non Steel III 1 m3/min Regen
12	Non Steel IV 1 m3/min
13	Non Steel V 4 m3/min
14	Non Steel VI 1 m3/min
15	Non Steel VII 1 m3/min Lab G
16	Non Steel VII 1 m3/min Lab H
17	Non Steel VII 1 m3/min Lab I
18	Non Steel VII 1 m3/min Lab J
19	Non Steel VII 1 m3/min Lab J Regen
20	Non Steel VII 1 m3/min Lab K
21	Non Steel VII 1 m3/min Lab L

Source: Hagino, in preparation for publication
Data not to be reprinted before submission for publication.
Data from JAMA.

- **The measurement of PN is complex and results are not consistent**

CONCERNS REGARDING PN

- Grey cast iron brake disc/
  Low Steel pads



1st run

2nd run

- **Two subsequent measurements of TPN with the <u>same</u> brake disc / pad have substantially different TPN results**

TPN* brake wear particle measurements not reproducible

- In contrast to the SPN** (Solid Particle number) TPN* is a newly introduced variable for which there is no established measurement and calibration procedure today. The draft GTR description for the TPN-measurement setup allows for major differences. Anything is permitted, from a setup with only one dilution stage with a dilution Rate of 1:10 up to a two dilution stage VPR-setup used in the exhaust gas measurement area (not actively heated) with dilution rate of 1:100 and higher.
- The PCRF calibration is not able to correct large differences that result from significantly different measurement setups and conditions.
- The consequence is that TPN measurement results from different brake wear particle test benches for the same brake differ significantly and cannot be reproduced.

- **TPN (Total Particle Number) brake wear particle measurements are not reproducible**
- **For TPN there is currently no established measurement procedure and calibration procedure. A reproducible determination does not appear to be feasible**
- **A determination of TPN is not expedient and should to be omitted from the GTR**

**Total Particle number emissions* (TPN10) means the number of total particles (i.e. solids and volatiles) at a nominal particle size of approximately 10 nm electrical mobility diameter and larger
***Solid Particle number emissions* (SPN10) - means the number of solid particles at a nominal particle size of approximately 10 nm electrical mobility diameter and larger

FAMILY BUILDING - GENERAL CONCEPT

- OICA supports a concept for family building
- OICA will support a dedicated TF to prepare these elements for the GTR

Family Building
General Concept

Input

One specific Brake-Combi:
Disc + Pad + Calliper

one individual vehicle

Family building

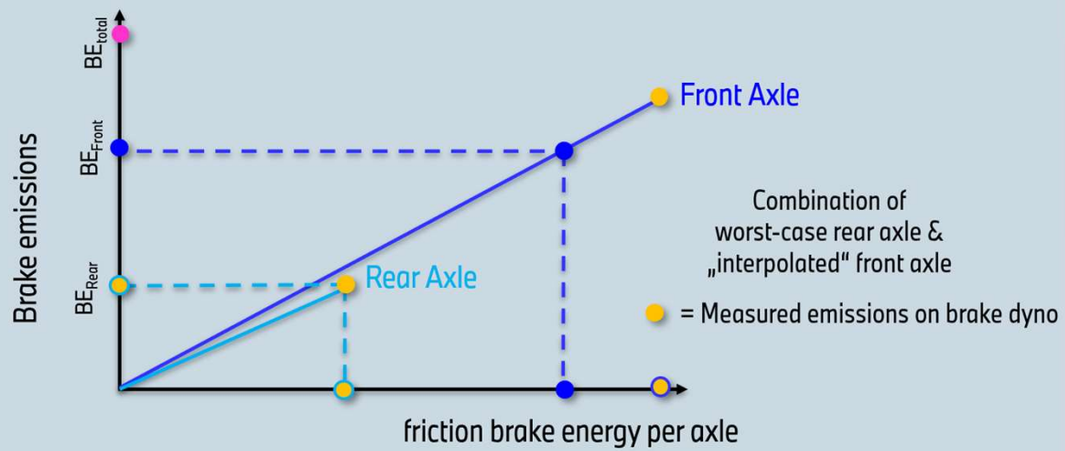
Currently, not possible to decide or know a priori,
which combinations of single brake parts will produce which quantity of brake emissions

… and to decide, which brake part combination will be the worst case
➔ Emission tests necessary

Per individual vehicle, brake emissions are the combination of front and rear axle results, ● + ● = ●
but very likely not simultaneously a combination of the two “worst case” brakes

Individual families per axle and each specific brake-combination necessary

Example: for individual vehicle,
Rear Axle friction energy is worst case
Front Axle is not worst case

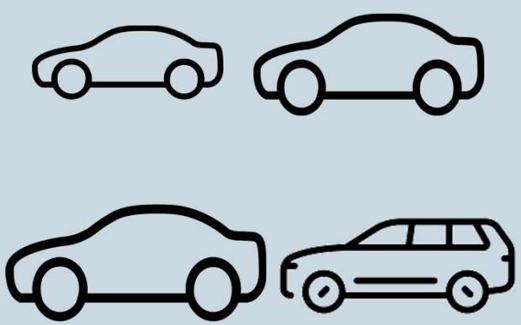


Family Building
General Concept

Input

One specific Brake-Combi:
Disc + Pad + Calliper

several specific vehicles



Family building

*BETF_H := Brake Emission Test Family High representative

- Interpolation based on total friction energy (per vehicle) on x-axis
- Only “Worst-Case” / vehicle “High (BETF_H)” member/vehicle tested on brake component test stand (●)
- If interpolation through origin (0,0) not allowed, 2nd test @ component test stand with vehicle with ca. 20-50% [tbd.] of “High” member required (◉)
- All other brake emissions (●) are interpolated based on calculated individual friction energy during WLTP brake
- One line (—) for One specific Brake-Combination: Disc + Pad + Calliper including different vehicles and different power train configurations
- OICA is intensively working on and discussing a common proposal